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Current status of "Dieless" Amino's incremental forming

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Abstract

The dieless NC forming process was developed in Japan as a flexible, alternative manufacturing method to effectively prototype stampings and produce panels in small lot in Japan. It is a numerically controlled incremental forming process that can form various materials into complex shapes. It is extremely cost effective as conventional tooling is not required and lead time is greatly reduced. Currently, incremental forming technology is attracting the attention as an effective method for small lot production and rapid prototyping.
This paper introduces the basics of the technology and shows the utilization of this process in industry by AMINO Corporation.

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Keywords: Incremental forming; Dieless NC forming; Prototype; Small lot production; Cost effective

1. Introduction

Dieless NC forming is a technique to form sheet metal into three dimensional shape and is an incremental forming technology. In incremental forming, the forming force is reduced. Therefore, it is possible to use the soft material such as plastics or wood for the model or die. Depending on the shape of the part it may possible to eliminate the die. This is why Amino calls this process "Dieless". This paper will identify examples of products which have been formed by dieless NC forming and make clear the current positioning and possibility of this method from actual cases.

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2. Development of dieless NC forming

2.1. Process of development

The origin of metal forming was the hammering of metal by hand. The crafting of Japanese swords has existed in Japan for over 1500 years. The process not only combines incremental forming with complicated heart-treatment, but also uses a lot of similar techniques exist in Japan.

In Japan with such a historical background, it is very normal that the incremental technology has developed and much research has been conducted earlier than most other countries.

2.2. Development of dieless forming technology and machines in AMINO

Fundamental principal of dieless forming was developed by professor Matsubara of Polytechnic University in early 1990s. In 1996, the development of the technology and forming machine was started. A research project was sponsored by the Japan Science and Technology Agency (JST) to foster new and original ideas.

AMINO Corporation developed the 1st prototype machine (Fig. 1) in 1996. AMINO also developed the CAM (Computer-Aided Manufacturing) software for Dieless forming in 1998. Since 2002 AMINO started to provide specialized equipment to industry globally. The total numbers of machines operation are over 30 units [2].

In addition AMINO has made over 3000 parts for R&D purposes.

Fig. 1. 1st. Prototype machine. (1996)

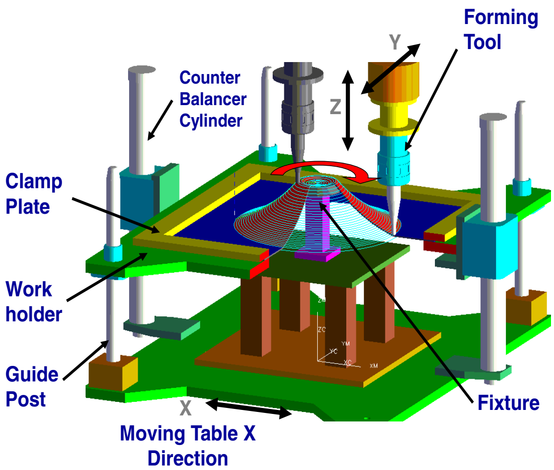

Fig. 2. Equipment drawing.

2.3. Forming description

The dieless system as shown by the Matsubara method is shown in Fig.2 [1- 3].

CAD math data for a panel is converted through CAM to NC, g-code data. It is downloaded to the machine controller 3-Axes Servo system. Material is securely clamped to a workholder such that there is no draw in from the binders.

The tool is actuated in the Z direction (Vertical). The workholder is counterbalanced to the vertical movement of the tool and is actuated in the X and Y direction. The fixed spherically tipped forming tool follows a two dimensional contour of the panel; incrementally forming the sheet from the math data. The tool descends a Z pitch and follows the next contour and so on, forming the part from top to bottom [1].

2.4. Forming principles

Nomenclature

A	original material length
θ	forming angle
B	stretched material length
A_1	the volume before forming
B_1	the volume after forming
t_0	original material thickness
t_1	formed material thickness

A sketch of the forming principals is shown in Fig.3. This model shows the cross section of the forming model. Fundamental principal for this process is material of length "A" is formed at angle "θ", and this material is stretched to length "B". In this process of forming, the volume "A_1" before forming is the same as volume "B_1" after forming. This means that the material thickness will be decreased as the length will be increased. The relation of forming angle and material thickness is referred to by Eq. (1) [3].

$$\text{Formed material thickness } t_1 = \text{ Original material thickness } t_0 \times \sin\theta \ . \tag{1}$$

For the purpose of theoretical understanding, Fig.4 below, shows the material thickness formed at 30°. The original material thickness was 0.975 mm.

The theoretical value of after formed panel thickness is 0.4875 mm from the formula. The actual measurement values with 12 samples are from 0.485 mm to 0.495 mm. This is in the range of 0.01 mm [1].

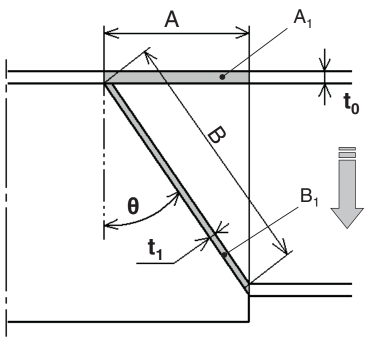

Fig. 3. Principle drawing.

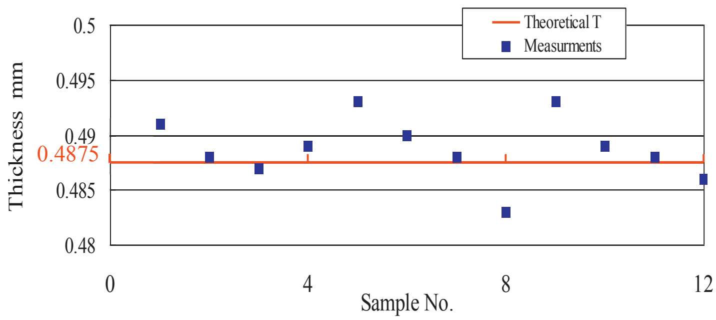

Fig. 4. Measurement of formed material thickness.

2.5. Characteristics of dieless forming

The characteristics of this forming method are derived from the principal of this process and the experience of various tests and tryouts are shown below [1, 2].

2.5.1. Lower material flow from flange

Fig. 5 is the sample of trapezoid shape of 200 mm height. It shows that there is almost no material draw-in from the flange area. In case of incremental forming there is very little wrinkles or surface distortion around the formed area. Therefore it becomes possible to form the required shape out the material without disturbing the material around the part.

2.5.2. Large material elongation

Fig. 6 is the sample of cone shaped flower pot. Material is A1050 and material thickness is 1.5 mm. The height of this cone is 220 mm and diameter of leader is φ6 mm. In case of conventional stamping the elongation happens locally in part at the lead in radius. It is impossible to draw such a shape with stamping. On the other hand, incremental forming can achieve large material elongation by the repeating of minute material deformations. In this case material elongation of up to 300% was achieved.

2.5.3. Lower die tooling cost

Fig. 7 shows the sample of variety of pyramid shapes panel. Material is A1050 and material thickness is 1.0 mm. Six different shapes (Cone, Square, Pentagonal, Hexagonal, Octagonal, Dodecagonal) are formed in one blank. The forming die for these shapes is very simple and consists of one base plate and six cylindrical posts. If the forming shape is two dimensional meaning a constant angle in Z direction, it is possible to form without master model. Even if the shape is three dimensional, it is possible to form part with a die made of plastics. This reduces tooling cost.

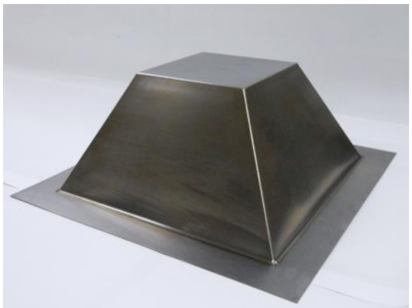

Fig. 5. Principle drawing.

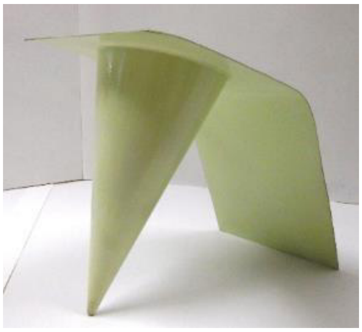

Fig. 6. Flower Pot.

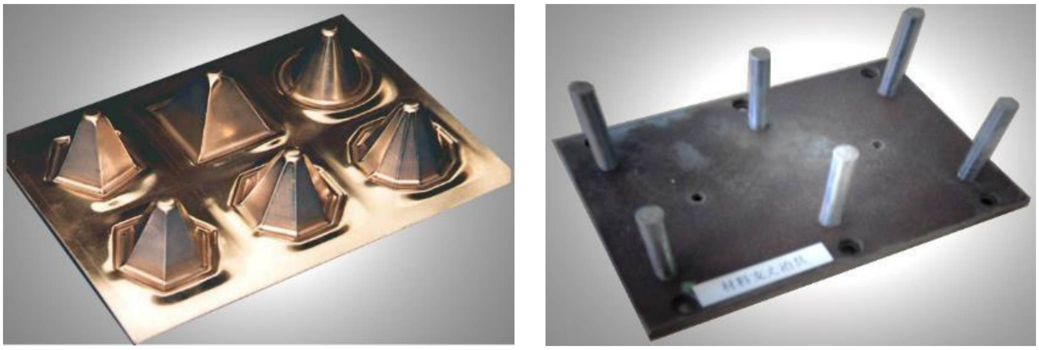

Fig. 7. Variety of pyramid shapes.

2.5.4. Improvement of strength and hardness

Fig.8 shows the comparison of material strength before and after forming with A5052-O. Taper angle is 30°, Material Thickness is 1.0mm. The tensile strength of material is 211 N/mm^2. After forming the strength will increase to 278 N/mm^2.

After the material reaches its yield strength, it will climb to the maximum stress immediately, and result in a failure. Material elongation decrease significantly after forming.

Fig. 9 shows the comparison of material hardness before and after forming. The Brunel hardness measurements were taken of both faces of material surface. Raw material has hardness of HB40 to HB50. It will increase to HB70 to HB80 after forming. These tendencies were confirmed in other materials tested. Such characteristics of this process widen the possibility to utilize this method to light weighting of parts, partial increasing strength or hardness [1].

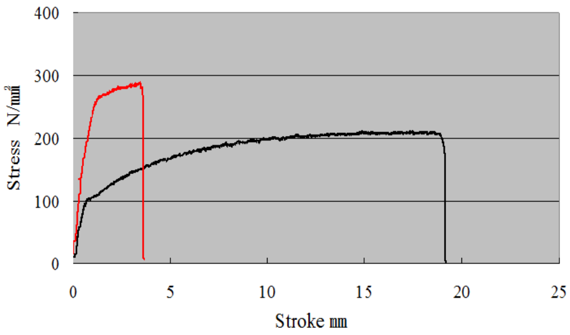

Fig.8 Comparison of material strength.

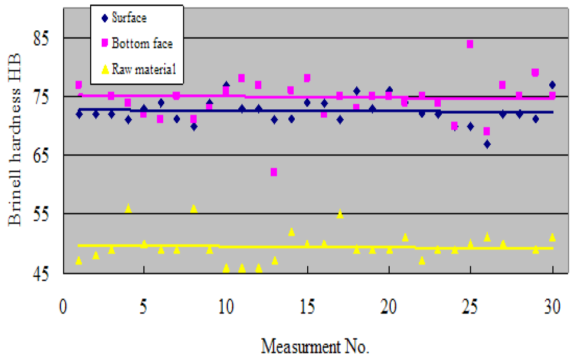

Fig. 9. Comparison of surface hardness.

3. Introduction of examples

3.1. Utilization to automotive service parts

For the automotive industry, the production of replacement panels for service is a very costly and time-consuming business. Tools to produce body panels are normally stored for a period of 10 to 20 years before being discarded. The cost of tool storage and pulling out the tooling to make a few panels a year is high. Incremental forming technology would seem ideally suited to reduce some of these burdens. In 2000 Honda Motor Co., Ltd. and Amino Corp. jointly began work to utilize dieless forming as possible production method for automotive replacement panels [4].

Fig. 10. Honda, S800.

Fig.11. 3D Scanner to data.

Fig.1 0 is the sixty era Honda S800. Honda would like to supply old model car owners with replacement parts. However, tooling or part drawings do not exist. Tension-dieless method was developed for the viable production method of S800 Hood assembly, outer skin, and inner panel.

At first, it was necessary to laser scan both surfaces and create surface data to drive the dieless process and create tooling. An old hood assembly was taken from a vehicle and a 3D laser measuring system was used to create point cloud as shown in Fig. 11. The surface data was created from 3D scan and used to dieless forming process. From the data, tools were constructed with composite materials and forming was performed. In this case, a modification to the basic dieless system was made to combine a stretch forming and dieless forming technique. A sheet is initially stretched formed over a model. And rough shape is formed by this stretch forming. For the defined feature that cannot be formed in the stretch process the dieless machine uses a hardened tool to incremental form the metal to the desired shape. Outer and inner panels are shown in Figa. 12 and 13. These panels were then laser trimmed and assembled, painted and mounted on an existing vehicle as seen in Fig. 14 [4].

Fig. 12. S800 Outer form, SPCE, t0.7mm.

Fig. 13. S800 Inner form, SPCE, t0.7mm.

Fig. 14. Mounted Hood Assy.

3.2. Additional forming to existing production panel for low volume production

Recently, Toyota Motor Corporation and Amino Corporation worked together on a project to provide specialty panels to low volume niche vehicles. The purpose was not to form panels from raw material but to use incremental forming on existing stamped panels to add features or style for special edition vehicle. Toyota Motor Corporation jelled it as their applied technology and they developed outer panels in their house for their specialty cars. In case of dieless forming, the demerit of process are tool path mark on the panel surface and long forming time. However, dieless forming adds flexibility to car exterior design with low tool cost.

In this project incremental forming is used as the secondary process after drawing, trimming and flanging of automotive panel. The process provides high style impact to the market at reasonable cost in tooling versus cost of forming and metal-finishing time of the tool marks. We are able to add new features that could not be formed by conventional tools or would be cost prohibitive. Fig.15 is the picture of TOYOTA iQ and Fig. 16 is super charger model iQ-GRMN.

Fig. 15. TOYOTA iQ.

Fig. 16. TOYOTA iQ-GRMN Super Charger
(The photography in Tokyo Auto Salon 2012)

It is a special edition vehicle that is not only high performance but also has unique exterior styling. Dieless forming samples of the modification to the iQ-GRMN panels are shown below.

3.2.1. Put LOGO mark to door panel

Usually logo mark for special edition vehicle is put with stickers or chromed plastic parts.

Fig.18 shows the door panels which is put GRMN logo mark by dieless forming into the existing door outer panel which shows in Fig. 17. It takes about a couple of ten minutes for the logo mark.

Fig. 17. Normal Door panel of TOYOTA iQ.

Fig. 18. Logo mark on Door panel of TOYOTA iQ-GRMN.

3.2.2. Sharpen the character lines and corner radius.

One of the current trends in the automotive industry is sharpen, crisp feature lines on the exterior panels.

Fig. 20 is an example of sharpening of an existing feature line. The original panel is shown in Fig. 19 and it has around 20 mm radius feature line in the draw process. Dieless forming sharpens it to less than 3.0 mm radius. It takes about a couple of ten minutes for several feature lines. In addition, the dieless process sharpens the door opening corner radius.

Fig. 19. Normal feature lines of TOYOTA iQ.

Fig. 20. Sharpen feature lines of TOYOTA iQ-GRMN.

3.2.3. Put mounting boss for over fender part

Fig. 22 is a sample of additional forming that put the mounting boss for an over fender plastic part. Not only for changing the shape of outer panel but also use for improvement of assembly work for other parts.

Fig. 21. Normal Side panel of TOYOTA iQ.

Fig. 22. Mounting boss on side panel of TOYOTA iQ-GRMN.

3.3. New field / thick material forming

The demand to use incremental forming for the frame parts with thick materials as well as thin panels is increasing. Under such requirement, Amino Corporation developed new forming machine that is suited to the thick materials or high strength materials (such as High Tensile Strength Steel and stainless steel) and improved the rigidity of the machine. The machine is shown in Fig. 23.

One of the big advantages of incremental forming process is that it can lower the required forming force. The force is reduced as it is forming incrementally as opposed to bulk forming. This allows us to minimize the size of machine and also the cost of initial investment like equipment or tooling. Fig. 24 is the forming of 4.5 mm thickness material of SPHC. In case of forming this part with press machine, it may need 8000 kN to 10000 kN class of press machine. On the other hand, incremental forming takes just about 25 kN.

Fig.25 is the example of forming of square tubes. Although there is still few cases of thick material forming, usage of incremental forming to the new field is expected in future.

Fig. 23. New machine (MORPH-01).

Fig. 24. t4.5mm SPHC sample.

Fig. 25. Samples of 50mm square tube forming.

4. Conclusions

The incremental forming technology is being studied widely, and the practical use of this technology has been gradually advanced as well.

We introduced the example of usage to the automotive service parts that are produced with combination process of the stretch draw forming and dieless forming and also the example of small lot specialty vehicle part which are formed additional shapes with dieless forming on the existing press part.

Dieless forming is well suited to produce prototype panel or small lot production panel and it is cost effective method and also it is possible to add merit of design flexibility with low tooling cost.

References

[1] M. Amino, M. Mizoguchi: Practical applications of the dieless NC forming for sheet metal", SOKEIZAI, 52-11 (2011), 2-7.
[2] H. Amino: Development of the dieless NC forming machine for a sheet metal", J. JSTP, 51-599 (2010), 1119-1123.
[3] S. Matsubara: Incremental backward bulge forming of a sheet metal with a hemispherical had tool -A study of a numerical control forming system II", J. JSTP, 35-406 (1994), 1311-1316.
[4] H. Amino, S. Ozawa: Dieless NC forming, prototype of automotive service parts", ICRPM Conference, (2002), 179-185.